Integrating Object Locations in the Memory Representation of a Spatial Layout[1]

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The present study investigated how object locations learned separately are integrated and represented as a single spatial layout in memory. Two experiments were conducted in which participants learned a room-sized spatial layout that was divided into two sets of five objects. Results suggested that integration across sets was performed efficiently when it was done during initial encoding of the environment but entailed cost in accuracy when it was attempted at the time of memory retrieval. These findings suggest that, once formed, spatial representations in memory generally remain independent and integrating them into a single representation requires additional cognitive processes.

Spatial learning in everyday environments involves remembering the layout of multiple objects. Because few environments are learned at a single fixation, visual learning of a spatial layout requires integrating sequentially learned object locations into a representation of the entire layout (e.g., Henderson & Hollingworth, 1998). The present study investigated how this integration occurs by examining differential effects of two spatial learning methods on subsequent memory representations of spatial layout.

Previously we have demonstrated that a spatial layout can be learned efficiently through sequential viewing of objects (Yamamoto & Shelton, 2007, in press). In these studies, stationary observers were presented with six objects (each in unique location) sequentially, one or two at a time. When they subsequently made judgments of relative direction among objects (JRDs), their performance was equivalent or even superior to that following simultaneous viewing of the entire layout. Because this task primarily requires knowledge of interobject spatial relations, these findings suggest that there was little cost in merging sequentially experienced object locations into a representation of the spatial layout.

However, previous studies have shown that object locations in a given space are often organized into several collective units in memory that are not easily integrated (e.g., Hirtle & Jonides, 1985; McNamara, 1986; Wang & Brockmole, 2003). For example, Wang and Brockmole demonstrated that judgments of egocentric direction were less accurate for familiar locations on a college campus than for object locations in the immediate surroundings (i.e., a room in a building on the campus), even after both types of target locations were learned to the same criterion. These results suggest that not all locations can be integrated into a single spatial representation, even when all of them could be located within the same spatial framework.

To resolve this discrepancy, two experiments were conducted in the present study. In Experiment 1, stationary participants (four males and four females) were presented with a room-sized layout of 10 objects, which was divided into two sets of five objects. These two sets did not share any objects or locations, but they were also not linearly separable within the larger room context. The participants were instructed to remember the layout of all 10 objects, not two separate layouts of five objects each. They were shown the first set for 30 sec, and asked to point and name the five objects with their eyes closed. They repeated this study-test sequence until they fluently pointed to correct object locations twice in a row. Then the just-viewed set was removed and the same procedure was repeated for the second set.

After the learning phase, the participants performed JRDs. Three objects in the learned layout formed each trial; e.g., "Imagine you are at the bag and facing the jar. Point to the vase."

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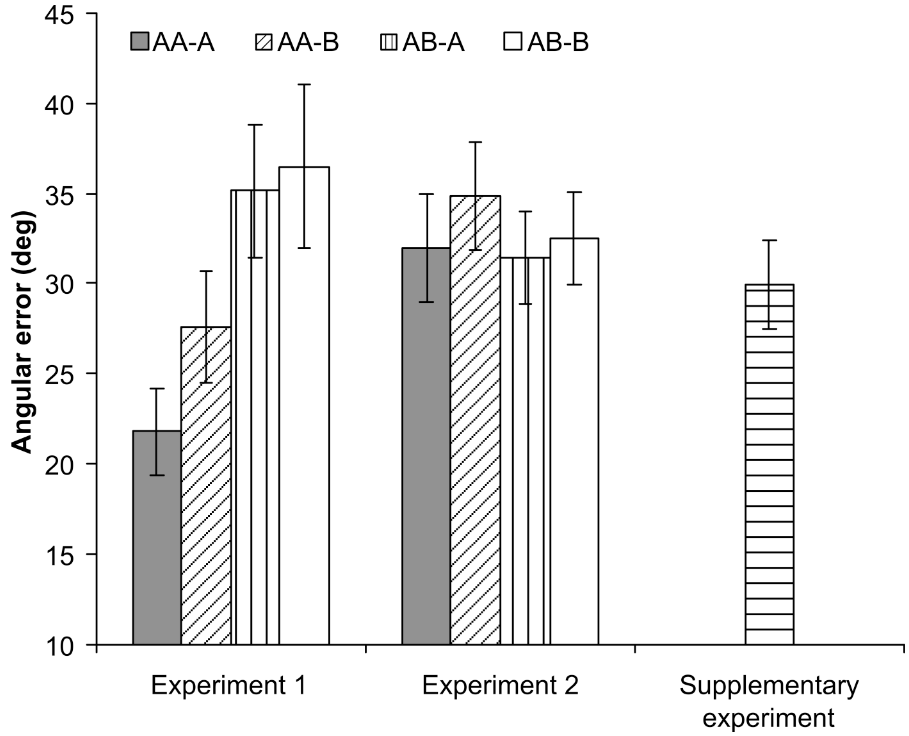

Figure 1. Mean absolute angular errors in judgments of relative direction (JRDs) as a function of JRD trial types. In AA-A trials, all three objects constituting a trial came from the same set. The first, second, and third letters in the label represent a base object, a facing object, and a target object in a JRD trial, respectively. The same identity shared by all three letters indicates that those objects belonged to the same set. In AA-B trials, an imagined heading was defined within each set and a target object was from the other set. In AB-A and AB-B trials, the imagined heading was made up with objects from both sets (one from each), and the target object belonged to the same set as either the base object or the facing object. Note that in these trial labels, A and B simply indicate whether each object came from the same or different set, and they do not refer to objects from specific sets. In the supplementary experiment no distinction was made in the JRD trial types (i.e., all 10 objects were presented simultaneously), and therefore the overall mean of all JRD trials is plotted. Error bars represent ±1 standard errors of the means.

The first two objects constituted an imagined heading. The third was a target. The major dependent variable was absolute angular error in pointing. The primary independent variable was the type of JRD trials: (1) all objects constituting a trial were from the same set (labeled as AA-A; for details of the trial labels, see the figure caption); (2) an imagined heading was defined by objects from the same set, and a target was from the other set (AA-B); and (3 and 4) an imagined heading was made up with objects from both sets (AB-A or AB-B). These types of JRD trials required the integration of two sets into a single layout to different degrees: AA-A trials could be performed without integration; AA-B trials required the integration only to find the target; and AB-A/AB-B trials necessitated the integration both for establishing the imagined heading and for locating the target. Therefore, by comparing performance in these different trial types, the present experiments explored how effectively two groups of object locations were integrated in memory. The JRD trials were presented in random order, and different imagined headings and target directions were counterbalanced.

Results showed that AA-A trials yielded most accurate JRDs, followed by AA-B and AB-A/AB-B trials in this order (see Figure 1), F (3, 18) = 5.86, p < .02. These results correspond to the differential amounts of required integration for each trial type, indicating that there was clear cost in integrating two sets into a single representation of the entire layout. That is, although participants were explicitly instructed to put two sets together into a single layout prior to the learning phase, and in addition, they viewed all objects in the same room from the fixed viewing position, such integration still required additional cognitive processes when each set was learned individually.

In Experiment 2, the same procedure and instructions as in Experiment 1 were used with the following modification: After viewing the first set once, it was removed and the second set was presented immediately, and then participants (four males and four females) pointed and named all 10 objects with their eyes closed. (In contrast, participants in Experiment 1 learned the first set to criterion, and then learned the second set to criterion.) By presenting two sets in succession and setting the learning criterion for the whole layout, this procedure was intended to facilitate the integration of two sets during the learning phase. Results showed that although overall accuracy was decreased, all trial types yielded equivalent performance (see Figure 1), $F < 1$. In addition, these JRDs were as accurate as those performed after viewing all 10 objects simultaneously (supplementary experiment; see Figure 1). Together, these results indicate that the integration of two sets was done with little cost in Experiment 2.

Because the key difference between Experiments 1 and 2 was whether two sets were learned individually or successively, the present findings suggest that integration of object locations into the representation of a single layout can be performed effectively if it is carried out during initial encoding of the environment. However, the same integration requires additional processes if it is attempted at the time of retrieval, suggesting that separately formed spatial representations remain independent in memory, even when those representations have a large overlap.

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